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DEVELOPMENT OF FLAME RESISTANT
METAL AND METAL-GLASS
BLENDED STRUCTURES

Contract No. NAS 9-7397

FINAL REPORT
December 1971

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Prepared by

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for

National Aeronautics and Space Administration
Manned Spacecraft Center
Crew Systems Division
Houston, Texas

December 1971

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INTRODUCTION

The purpose of this program has been the design and fabrication of candidate flame-resistant woven and knitted fabrics, tapes, webbings and cords as replacements for those items used in the Apollo spacecraft which were previously made of nylon and polyester. Structures made from Chromel R metal fibers (74% Ni, 20% Cr, 2-1/2% Fe, 2-1/2% Al, 1/2% Si, 1/2% Mo), Beta glass fibers and high-temperature organic fibers such as PBI (polybenzimidazole) were developed and evaluated. The feasibility of improving the performance of selected fabrics by using CNR (carboxy nitroso rubber) or other nonflammable coatings were also investigated.

Since its inception, work on the program has involved a number of technical tasks which were eventually completed or the work discontinued at NASA request. A listing of disposition of the various tasks assigned during the course of the program is given below.

Task No.	Description	Initiation Date	Completion Date	Monthly Report Reference
1	Produce Miscellaneous Fibrous Metallic Structures	8/29/67	Mar 68	Oct 67 - Apr 68
2	Study Flammability of Metal Structures	8/29/67	Nov 67	Aug 67 - Dec 67
3	Produce Sample LCG Fabrics	8/29/67	Apr 68	Oct 67 - May 68
4	Produce Metal Fabric for PGA	8/29/67	Apr 68	Oct 67 - May 68
5	Produce LCG Metal Liner Fabric	8/29/67	Mar 68	Oct 67 - Apr 68
6-9	-----	deleted	-----	-----
10	Develop Metal and PBI Tie-Down Webbings	12/20/67	Apr 68	Oct 67 - May 68
11	Produce 100 yards of PBI Restraint Harness	12/20/67	Dec 67	Oct 67 - Jan 68
12	Produce 50 Yards of Combination Beta Glass-Nomex Fabric	12/20/67	Feb 68	Oct 67 - Mar 68
13	Develop CNR Coated Beta Fabric Samples	12/20/67	May 68	Oct 67 - Jun 68
14	Produce 50 Feet of PBI Restraint Cord	12/20/67	Jan 68	Nov 67 - Feb 68
15	Produce 20 Feet of PBI In-Flight Exerciser Materials	12/23/67	Nov 67	Nov 67 - Dec 67
16	Produce 5 Yards of PBI Raschel Fabric for Debris Net	12/28/67	Nov 67	Nov 67 - Dec 67

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
17	Develop Fluorel Coated Beta Fabrics	12/30/67	Jun 69	Nov 67 - Jul 69
18	Produce 40 Feet of 1-3/4 Inch PBI Webbing	1/15/68	Nov 67	Nov 67 - Dec 67
19	Study Application of CNR to Beta Yarn	1/30/68	Nov 68	Jan 68 - Dec 68
20	Produce 50 Yards of Elastic Tape for CNR Stretch Yarn	1/30/68	Aug 68	Jan 68 - Sep 68
21	Develop Fluorel Coated Beta Yarn	1/30/68	May 69	Jan 68 - Jun 69
22	Develop Fluorel Coated PBI Yarn	1/30/68	Jan 68	Jan 68 - Feb 68
23	Produce 1 Nonflammable Thermal Insulating Blanket	1/30/68	Apr 68	Jan 68 - May 68
24	Produce PBI Rope and Webbing	1/30/68	May 68	Feb 68 - Jun 68
25	Produce 100 Yards of Woven and Knitted Fabric from Teflon Coated Beta Yarn	1/30/68	Sep 68	Feb 68 - Oct 68
26	Produce 450 Yards 1 Inch Wide PBI Webbing	1/30/68	Feb 68	Feb 68 - Apr 68
27	Produce 100 Feet of 1/8 Inch PBI Braided Cord	1/30/68	Jan 68	Feb 68
28	Produce Miscellaneous Beta Structures	2/14/68	Apr 68	Mar 68 - May 68
29	Produce 300 Yards Woven Fabric from Teflon Coated Beta Yarn	2/16/68	Jun 68	Mar 68 - Jul 68
30	Produce 50 Yards Raschel Net from Teflon Coated Beta Yarn	2/19/68	Apr 68	Mar 68 - May 68
31	Produce 400 Yards of 1-3/4 Inch Wide PBI Webbing	3/27/68	Apr 68	Apr 68 - May 68
32	Produce 100 Feet of 3/8 Inch Wide Tape from Fluorel Coated Beta Yarn	3/27/68	Nov 68	Apr 68 - Dec 68

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
33	Produce 100 Yards Woven Fabric from Teflon Coated Beta Yarn	4/ 1/68	Jun 68	Apr 68 - Jul 68
34	Produce 700 Yards Woven Fabric from Teflon Coated Beta Yarn	4/23/68	Jun 68	Apr 68 - Jul 68
35	Study Various Methods for Teflon Coating Beta Yarn	5/ 2/68	Sep 68	May 68 - Oct 68
36	Produce 60 Yards 13/16 Inch PBI Webbing	5 8/68	May 68	Jun 68
37	Produce 15 Pounds 3-Cord PBI Sewing Thread	5/ 8/68	May 68	Jun 68
38	Produce 250 Yards 1-3/4 Inch Wide PBI Webbing	5/16/68	Jun 68	Jun 68
39	Produce Miscellaneous Metal Structures	5/19/68	Jun 68	Jun 68
40	Produce 50 Yards PBI Circular Knit Sleeving	5/23/68	Jun 68	Jun 68
41	Produce 100 Yards Coreless Braid from Teflon Coated Beta Yarn	6/20/68	Jun 68	Jul 68
42	Produce Miscellaneous Double Coated Fabrics	9/20/68	Jul 69	Jul 68 - Jul 69
43	Produce 200 Feet PBI Braided Cord	9/20/68	Jul 68	Jul 68
44	Produce 400 Yards 1-1/4 Inch PBI Webbing	9/20/68	Dec 68	Jul 68 - Jan 69
45	Produce Ten 62 Inch Lengths of Fluorel Encapsulated Beta Webbing	9/20/68	Nov 68	Sep 68 - Dec 68
46	Produce 1000 Yards PBI Braided Cord	9/20/68	Aug 68	Sep 68
47	Produce 4000 Yards PBI Braided Cord	9/20/68	Oct 68	Sep 68 - Oct 68
48	Produce 200 Yards Braided Cord from Teflon Coated Beta Yarn	10/ 2/68	Sep 68	Oct 68

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
49	Develop and Produce 50 Yards of Raschel Knit Debris Net from Teflon Coated Beta Yarn	10/11/68	Dec 68	Oct 68 - Dec 68
50	Produce 5000 Yards Braided Cord Identical to FRL Style No. S-127 (FRL Sample No. 397-163) as produced under Task 48	10/14/68	Dec 68	Oct 68 - Dec 68
51	Produce 800 Yards of 1 Inch Wide PBI Webbing Identical to FRL Style No. S-101 as produced under Task 24	11/26/68	Dec 68	Dec 68 - Jan 69
52	Produce 275 Yards of 1-1/4 Inch Wide PBI Webbing Identical to FRL Style No. S-124 as Produced under Task 44	11/29/68	Dec 68	Dec 68 - Jan 69
53	Produce 600 Yards of 1 Inch Wide PBI Webbing Identical to FRL Style No. S-124 as Produced under Task 26	12/31/68	Feb 69	Jan 69 - Feb 69
54	Develop and Produce Three 7 Yard Experimental Bi-Component Fabrics from Teflon and Teflon Coated Beta Yarns	1/ 6/69	Sep 69	Jan 69 - Sep 69
55	Produce 200 Yards of 1/4 Inch Diameter PBI Braided Cord Identical to FRL Style No. S-109 as Produced under Task 24	1/13/69	Feb 69	Jan 69 - Mar 69
56	Produce 100 Yards of 1-1/4 Inch Wide PBI Webbing Identical to FRL Style No. S-124 as Previously Produced under Tasks 44 and 52	1/22/69	Feb 69	Feb 69 - Mar 69
57	Fabricate two 50 Foot Lengths of 3 Inch Flat Width Knitted Sleeving for R.E. Darling Company using Beta Yarns and 2-Mil Copper Wire	2/ 5/69	Jul 69	Feb 69 - Aug 69
58	Fabricate Slide Fasteners from 500 Yards of Woven Bleached Teflon Tape	3/ 3/69	May 69	Mar 69 - Jun 69

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
59	Produce 7 Yards of Woven Broad Fabric from Bundle Drawn Karma Yarn	3/10/69	Apr 69	Mar 69 - May 69
60	Produce 10 Pounds of Plied, Bleached Teflon Yarn Suitable for the Manufacture of Embroidered Name Tags	3/14/69	Apr 69	Mar 69 - Apr 69
61	Produce 7 Yards of Woven Broad Fabric from Bundle Drawn Karma Yarn (74 x 74)	4/ 8/69	Apr 69	Apr 69
62	Fabricate 12 Dozen Pairs of Cotton Wristlets	5/ 8/69	May 69	Apr 69 - May 69
63	Investigate "Limiting Oxygen Index" Technique to Determine Applicability to the Apollo Program	6/ 5/69	Jun 69	May 69 - Jun 69
64	Produce 7 Yards of Woven Broad Fabric from Texturized Bleached Teflon Yarn	6/10/69	Sep 69	May 69 - Oct 69
65	Fabricate 100 Yards of 1 Inch Wide PBI Webbing Identical to FRL Style No. S-111 as Produced under Task 51	6/17/69	Jul 69	May 69 - Jul 69
66	Fabricate Sample Yardage of 1 Inch PBI Webbing Similar to FRL Style No. S-111 Except that Metal Yarn will be Incorporated Into the Structure at Discrete Locations	6/23/69	Jul 69	May 69 - Jul 69
67	Produce 7 Yards Broad Woven Spun PBI Fabric	7/ 2/69	Aug 69	Aug 69 - Sep 69
68	Produce 7 Yards Broad Woven Bleached Teflon Fabric (2 x 2 HBT, 1/4 inch reversal)	7/16/69	Sep 69	Aug 69 - Oct 69
69	Produce 7 Yards of 3/4 Inch Wide PBI Webbing Similar to FRL Style No. S-124 (Lot 397-140)	8/ 1/69	Aug 69	Aug 69
70	Study Feasibility of Applying Dynatech Fluorel Formulation to Continuous Filament PBI Yarn	8/13/69	Sep 69	Aug 69 - Oct 69

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
71	Produce 100 Yards of 1/4 Inch PBI Braid Similar to FRL Style No. S-109	8/21/69	Aug 69	Sep 69
72	Develop Improved Glove Materials for use in the Lunar Receiving Laboratory Vacuum Chamber	8/28/69	Sep 69	Sep 69 - Oct 69
73	Produce 7 Yards of PBI Webbing Conforming to Constructional Characteristics of Type V of Military Specification MIL-T-8363A	9/ 2/69	Sep 69	Sep 69
74	Expansion of Work Performed under Task 72	9/17/69	Sep 69	Oct 68
75	Produce 10 Yards of Open Mesh Continuous Filament PBI Tricot for Polymer Reinforcement	9/17/69	Oct 69	Oct 69
76	Produce 15 Yards of Raschel Knit Fabric for Blankets Using 450 1/3 Teflon Coated Beta Yarn	9/17/69	Oct 69	Oct 69 - Nov 69
77	Produce 15 Yards of Raschel Knit Fabric for Bankets using 200 Denier Continuous Filament PBI Yarn	9/25/69	Oct 69	Oct 69
78	Produce 7 Yards of 1 Inch Wide Continuous Filament PBI Webbing (0.050-0.080 inch thick) Similar to FRL Style No. S-111	10/ 2/69	Oct 69	Oct 69
79	Produce 30 Yards of Raschel Knit Fabric for Blankets using 450 1/2 Teflon Coated Beta Yarn	10/23/69	Dec 69	Nov 69 - Dec 69
80	Produce 100 Yards of 1 Inch Wide PBI Webbing Identical to FRL Sample No. 397-224, FRL Style No. S-141, Previously Delivered under Task 78	11/14/69	Nov 69	Nov 69 - Dec 69
81	Produce 7 Yards of 1-1/2 Inch Wide PBI Webbing Identical in Construction to FRL Style No. S-141 Previously Delivered under Task 78	11/15/69	Nov 69	Nov 69

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
82	Produce 100 Feet of 3/4 Inch Wide PBI Webbing Identical in Construction to FRL Sample No. 397-212 Previously Delivered under Task 69	11/19/69	Nov 69	Dec 69
83	Produce 20 Yards of 8 oz/sq yd Spun Durette Broad Fabric (2 x 2 HBT, 1/4 inch reversal)	11/28/69	Mar 70	Dec 69 - Apr 70
84	Fabricate 2 spun PBI knit Shirts	12/ 3/69	Dec 69	Dec 69 - Jan 70
85	Produce 50 Yards of 3/4 Inch Wide PBI Webbing Identical to FRL Sample No. 397-216 Previously Delivered under Task 73	11/12/69	Dec 69	Dec 69 - Jan 70
86	Fabricate 200 Yards of Bleached Teflon Zipper Tape Identical to FRL Sample No. 397-208, Style No. S-134 Previously Delivered under Task 58	11/22/69	Feb 70	Jan 70 - Mar 70
87	Produce 75 Yards of 1-1/2 Inch Wide PBI Webbing Identical to FRL Sample No. 397-249, Style No. S-143 Previously Delivered under Task 81	12/17/69	Feb 70	Jan 70 - Feb 70
88	Produce 7 Yards of 1-1/2 Inch Wide Nomex Webbing Identical in Construction to PBI Webbing (FRL Style No. S-143) Previously Delivered under Tasks 81 and 87	1/23/70	Jan 70	Feb 70
89	Fabricate Component Materials and Clothing for The McDonnell Douglas 90-day Manned Chamber Test	2/17/70	May 70	Mar 70 - May 70
90	Produce 20 Square Yards of PBI Knit Glove Fabric	3/ 4/70	May 70	Mar 70 - May 70
91	Produce Components for SKYLAB Garments	3/25/70	May 70	Apr 70 - May 70
92	Produce 250 Yards of 1-1/4 Inch Wide PBI Webbing Identical to Style No. S-124 Previously Delivered under Task 44	4/ 1/70	May 70	Apr 70 - May 70

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
93	Fabricate Additional Garments for the McDonnell Douglas Chamber Test	4/16/70	May 70	Apr 70 - May 70
94	Produce 50 Yards of 1/2 Inch Wide PBI Trim Tape for SKYLAB Garments	5/ 1/70	May 70	May 70
95	Produce 150 Feet of 1/2 Inch Wide PBI Webbing Identical to Style No. S-144 Previously Delivered under Task 82.	5/22/70	May 70	Jun 70
96	Produce 35 Yards of Broad Woven Spun PBI Fabric Identical to FRL Sample No. 397-317 Previously delivered under Task 91	6/ 9/70	Aug 70	Jun 70 - Aug 70
97	Purchase 100 Pounds of PBI Staple Fiber	7/ 6/70	Dec 70	Jul 70 - Dec 70
98	Durettize Dope Dyed Nomex Tricot Fabric	7/10/70	Jul 70	Jul 70
99	Conduct a Laboratory Study to Evaluate the Relative Physical Properties of PBI, Nomex, Durette, and Fypro Fabrics	7/14/70	Aug 70	Jul 70 - Aug 70
100	Produce 14 Pounds of Continuous Filament PBI Sewing Thread	8/17/70	Aug 70	Aug 70
101	Produce PBI Woven and Knitted Fabrics for SKYLAB Experiment T013	8/17/70	Aug 70	Aug 70
102	Fabricate 600 Feet of Teflon Coated Twisted Metal Lacing Cord for IVPG	8/21/70	Dec 70	Sep 70 - Dec 70
103	Fabricate PBI Braid for Possible use as a Life Support Tether in the SKYLAB program	10/ 7/70	Oct 70	Oct 70
104	Produce PBI Braids for SKYLAB Tether (continuation of Task 103)	10/23/70	Nov 70	Nov 70
105	Fabricate One PBI Braided Tether for AiResearch Corp.	11/16/70	Nov 70	Nov 70 - Dec 70

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
106	Fabricate 7 Yards of 1-1/2 Inch Wide Nomex Webbing	11/19/70	Nov 70	Dec 70
107	Laboratory Evaluation of Durettized Nomex/Stainless Steel Blended Fabric	12/14/70	Feb 71	Jan 71 - Feb 71
108	Fabricate 50 Yards of 1-3/4 Inch Wide PBI Webbing	1/11/70	Mar 71	Feb 71 - Apr 71
109	Fabricate 50 Yards of 1-1/2 Inch Wide Nomex Webbing	1/13/71	Jan 71	Feb 71
110	Fabricate 150 Yards of 1-1/4 Inch Wide PBI Webbing	1/19/71	Jan 71	Feb 71
111	Fabricate 50 Yards of 1-1/2 Inch Wide PBI Webbing	1/28/71	Feb 71	Feb 71
112	Produce 100 Yards of 1 Inch Wide PBI Webbing Identical to FRL Style No. S-101	2/10/71	Mar 71	Mar 71 - Apr 71
113	Produce 6 Pounds of 3-Ply PBI Sewing Thread Identical to FRL Style No. S-152	2/ 4/71	Mar 71	Mar 71
114	Fabricate 25 Yards of 1-Inch Wide PBI Webbing Identical to FRL Style S-141 and Compare Its Tensile Properties to Those Obtained for FRL Sample No. 397-250	2/25/71	Mar 71	Mar 71
115	Produce 5 Yards of Knit Fabric using PBI Wrapped Spandex Yarn	3/11/71	Jun 71	Mar 71 - Jun 71
116	Fabricate 100 Feet of 2-Inch Wide PBI Webbing Similar to FRL Style No. S-143	3/22/71	May 71	Apr 71 - May 71
117	Fabricate 50 Yards of 1-1/4 Inch Wide PBI Webbing Identical to FRL Style No. S-154	3/26/71	May 71	Apr 71 - May 71
118	Fabricate two PBI Woven Fabrics and a PBI Raschel Knit for a Prototype SKYLAB Sleep Restraint Assembly	4/19/71	Jun 71	May 71 - Jun 71

<u>Task No.</u>	<u>Description</u>	<u>Initiation Date</u>	<u>Completion Date</u>	<u>Monthly Report Reference</u>
119	Conduct a Study of Experimental Assemblies which may be Potentially Useful as an Ablative Layer on the Leading Edges of the Space Shuttle Vehicle	4/20/71	May 71	May 71
120	Develop a Prototype Flexible Fibrous Textile Structure Suitable for Providing Thermal Protection in a High Temperature, High Gas Velocity Environment	4/23/71	May 71	May 71
121	Fabricate 25 Yards of 3/8 Inch Wide PBI Tape	5/ 3/71	Jul 61	May 71 - Jul 71
122	Fabricate 350 Yards of 1/4 Inch Diameter PBI Braided Cord Identical to FRL Style No. S-109	5/20/71	Jul 71	Jun 71 - Jul 71
123	Fabricate 150 Yards of 1 Inch Wide PBI Webbing Identical to FRL Style No. S-101	5/20/71	Jul 71	Jun 71 - Jul 71
124	Develop Prototype Ablative Heat Shield Samples Based upon Card Clothing Principle	6/ 4/71	Aug 71	Jun 71 - Aug 71
125	Fabricate 50 Yards of 1-1/2 Inch Wide PBI Webbing Identical to FRL Style No. S-143	6/10/71	Jul 71	Jun 71 - Jul 71
126	Fabricate 75 Yards each of 2 Nomex Webbing Identical to FRL Style Nos. S-101 and S-141 for Conversion into X-420 materials by Monsanto	6/10/71	Jul 71	Jun 71 - Jul 71
127	Determine Tensile Characteristics of Monofilament and Multifilament "Halar" Yarns	7/13/71	Aug 71	Aug 71
128	Fabricate 100 Yards of 1-1/4 Inch Wide PBI Webbing Identical to FRL Style No. S-124	7/21/71	Sep 71	Aug 71 - Sep 71
129	Fabricate Woven and Knitted PBI Fabrics for MDAC-W Sleep Restraint Units	7/29/71	Sep 71	Aug 71 - Oct 71
130	Fabricate 200 Yards of 1-Inch Wide PBI Webbing (FRL Style No. S-141) and 7 Yards of 3/4-Inch Wide PBI Webbing Identical to FRL Sample No. 397-212.	8/10/71	Sep 71	Aug 71 - Sep 71

Task No.	Description	Initiation Date	Completion Date	Monthly Report Reference
131	Fabricate 7 Yards of 3/4 Inch Wide PBI Webbing Identical to FRL Sample No. 397-434, Style No. S-166	8/17/71	Sep 71	Sep 71
132	Provide 2 Test Samples from Carbonized 3D Rayon Fabric for Evaluation as a Flexible Ablative Head Shield	8/24/71	Dec 71	Sep 71 - Dec 71
133	Fabricate 25 Yards of 1-1/4 Inch Wide PBI Webbing Identical to FRL Style No. S-154 Previously Delivered	9/17/71	Dec 71	Oct 71 - Dec 71
134	Chemical Treatment of PBI, Durette and Nomex Fabrics to Reduce Their Flammability in Oxygen Enriched Environments	9/24/71	Dec 71	Oct 71 - Dec 71
135	Fabricate 75 Yards of 1-1/4 Inch Wide PBI Webbing Duplicating the Physical Characteristics of FRL Style No. S-154 but using 200 Denier PBI Instead of 260	9/28/71	Dec 71	Oct 71 - Dec 71
136	Fabricate 5 PBI Webbing and 1 PBI Braided Cord as Follows: 1. S-121, 3/32 braided cord 2. S-143, 1-1/2" webbing 3. S-169, 1-3/4" webbing 4. S-141, 1" webbing 5. S-157, 2" webbing 6. S-170, 1-3/4" webbing	10/ 5/71	Dec 71	Oct 71 - Dec 71
137	Fabricate 2 Sets of Various Slide Fasteners from FRL Style No. S-134 Teflon Tape Chain with <u>Natural Brass Teeth</u> for MDAC-W Prototype Sleep Restraints	10/13/71	Nov 71	Nov 71
138	Fabricate 50 Yards of 3/4 Inch Wide PBI Webbing Identical to FRL Style No. S-166	11/ 4/71	Nov 71	Nov 71 - Dec 71
139	Fabricate Multiple Sets of Slide Fasteners from FRL Style No. S-171 Teflon Tape Chain with <u>Aluminum Teeth</u> for MDAC-W Sleep Restraints	11/ 4/71	Dec 71	Nov 71 - Dec 71
140	Fabricate 100 Yards of 1/2 Inch Wide PBI Tape Identical to FRL Style No. S-144	11/22/71	Nov 71	Dec 71